Electromagnetic Susceptibility Characterization Test Report

for

Power Electronics Building Block Gate Drive and MCT Circuit

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1.0 ADMINISTRATIVE DATA

1.1 Purpose

The purpose of these tests was to determine the electromagnetic susceptibility characteristics of the PEBB Gate Drive and MCT circuit with respect to the requirements of MIL-STD-461D.

1.2 Test Requirements

The tests listed in Table 1.1 were performed in accordance with the methods described in MIL-STD-461D and MIL-STD-462.

TABLE 1.1 EMI Susceptibility Test Requirements

MIL-STD 461D REQ.	**MIL-TD 461D PAR #**	**DESCRIPTION**
CS114	5.3.9	Conducted Susceptibility, 10 kHz to 400 MHz, bulk cable injection
CS116	**5.3.11**	Conducted Susceptibility, Damped Sinusoidal Transients
RS101	**5.3.15**	Radiated Susceptibility, 30 Hz to 100 kHz, Magnetic Field
RS103	**5.3.16**	Radiated Susceptibility, 10 kHz to 18 GHz, Electric Field

1.3 Test Performance Information

The tests listed in the previous section were performed at the Naval Surface Warfare Center, Carderock Division (NSWCCD) Code 9532 EMC Lab, Bldg. 601 U.S. Naval Base, Philadelphia, PA 19112.

The period of testing was 23-29 Feb. 1997

The following personnel were involved in the performance of these tests:

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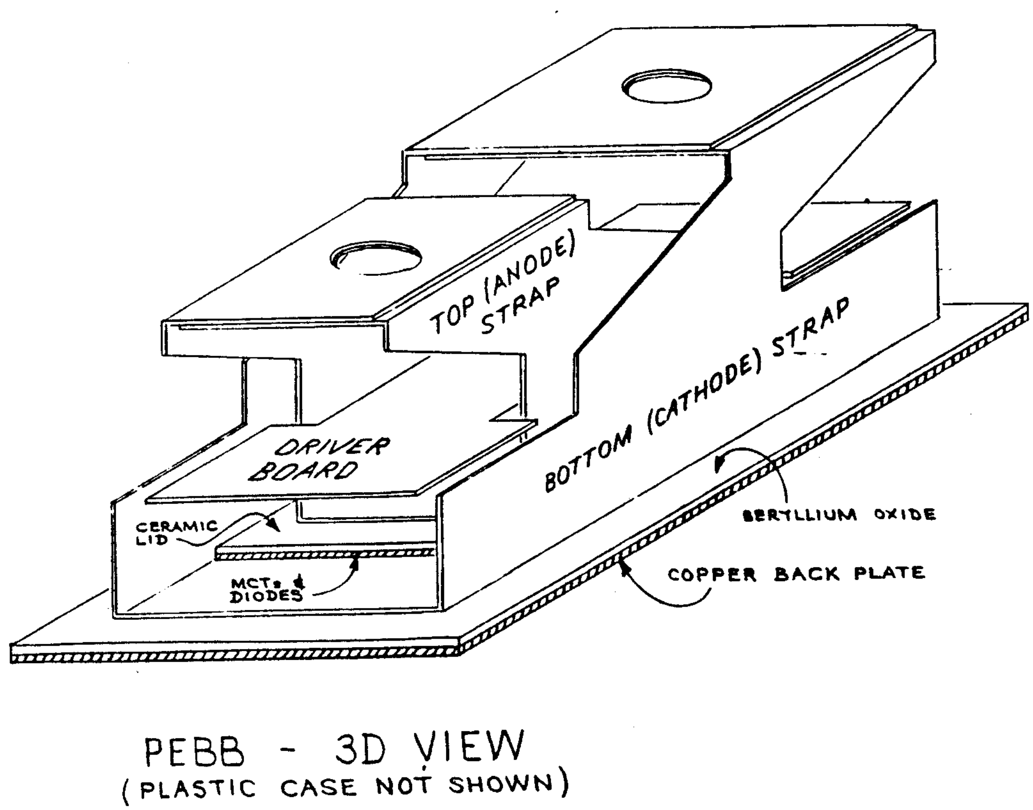
2.0 DESCRIPTION OF EQUIPMENT UNDER TEST

In the text and drawings that follow, the PEBB circuit will sometimes be referred to as EUT (Equipment Under Test).

The PEBB system is a modular electronics based power conditioning / distribution system designed to couple large power handling capabilities and programmable variable function control in a physically small package. Utilizing advances in semiconductor technology and fast gated switching devices the PEBB system has evolved from theory to the developmental stage. The portion of the system tested here was the Gate Drive Circuit and MCT module (see Figure 2.1). These tested elements form the core of the PEBB system. The system as tested consisted of the Gate Drive with simulated control power (DC) and simulated fiber optic control input. The Gate Drive connected to the MCT via ribbon cable similar to the current intended installation.

Figure 2.1 Conceptual PEBB Drawing



3.0 TEST SUMMARY

3.1 Results

The EUT was tested to the appropriate limits of MIL-STD-461D as detailed in this document.

Listed below is a summary of the results for this EUT.

TEST	***RESULT***	***PARAGRAPH***
CS114	FAILED	9.1
CS116	FAILED	9.2
RS 101	PASSED	9.3
RS 103	FAILED	9.4

Particular test information, graphic results and test data sheets are contained in the paragraphs indicated.

4.0 APPLICABLE DOCUMENTS

4. 1 Military

MIL-STD 461D 11 Jan 1993	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD 462 11 Jan 1993	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-45662A 1 Aug. 1988	Calibration Systems Requirements
MIL-STD-285 25 Jun. 1956	Method of, Attenuation Measurement of Enclosures, Electromagnetic Shielding, for Electronic Test Purposes

5.0 TEST SITE

5.1 Test Chamber

The tests described herein were performed at the Naval Surface Warfare Center, Carderock Division (NSWCCD) Code 9532 EMC Lab, Bldg. 601 U.S. Naval Base, Philadelphia, PA 19112.

A 20' x 20' x 10' full anechoic chamber was utilized for all tests. This chamber provided a minimum of 105 dB of attenuation to electric fields from 10 kHz to 100 MHz, plane waves from 100 MHz to 1 GHz and microwaves from I GHz to 10 GHz. The chamber provided a minimum magnetic field attenuation of 50 dB from 5 kHz rising to 100 kHz. The attenuation characteristics meet or exceed those of MIL-STD-285 and NSA 65-6. Test profiles of the attenuation factors can be found in Test Report 9319G, Shielding Effectiveness Test Report, Shielding Performance Services.

All input power to the room was filtered at its point of entry. The filters provided a minimum of 100 dB of attenuation from 10 kHz to 10 GHz. 115 VAC 30 amp service provided power to the Equipment Under Test (EUT).

5.2 Ground Plane

The ground plane for this test was a copper covered bench, 10' x 3'. The copper sheet was extended to the floor of the test chamber at one end of the table and bolted (one screw every three inches) to bond the table top to the shielded enclosure.

5.3 Mounting and Bonding

The EUT was not bonded to the ground plane.

5.4 Test Instrumentation Isolation

All test instrumentation was isolated from the EUT via isolation transformers.

6.0 TEST INSTRUMENTATION

The test instrumentation utilized for each test is listed in the appropriate paragraph. The information descriptions include the manufacturer, model number, serial number and calibration due date.

7.0 EUT SYSTEM SETUP FOR TEST

This section details the general test sample setup for all of the specified tests. Detailed test configurations particular to each individual test are contained in the appropriate paragraph.

A setup photograph of the EUT is given as Figure 7.1. This figure shows the setup of the EUT on the ground plane, input power and interconnecting cable configuration and the configuration of equipment that, while not part of the EUT, was necessary to make the EUT function as intended. All equipment located within the test chamber which is not part of the EUT was configured so as to minimize any emission characteristics. Any emissions produced were considered part of the ambient.

Non-EUT equipment to be located within the test chamber for the testing of AC switches consisted of a DC Power. This auxiliary equipment was necessary to allow the EUT to perform its normal function and provide indication as to proper operation. When performing radiated tests the power supply unit (PSU) was enclosed in a steel box, bonded to the ground plane minimize the effects of the radiated fields on the power supply (as shown in Figure 7.2).

Figure 7.1: Basic System Configuration

Figure 7.2: Power Supply Enclosure

8.0 EUT OPERATION DURING TEST

8.1 Modes of Operation

Testing was performed on the EUT in one mode: *operating*. This entailed setting the EUT on 2X4s above the ground plane, connecting the input to the Gate Drive to the output of the PSU. The PSU output was set for +/-24 VDC, producing a +/-15 VDC square wave to the EUT.

8.2 Performance Verification

Prior to the start of each test the EUT was tested to verify that the EUT was functioning in an acceptable manner. The procedure for this included:

1. Energizing the EUT via input power fed from the PSU;
2. Noting the square wave was present at the EUT at the proper amplitude. This was monitored on a digital oscilloscope via a remote camera (as shown in Figure 8.1).

Figure 8.1: Performance Monitoring Equipment

8.3 Susceptibility Pass/Fail Criteria

The EUT was considered to be functioning properly when the square wave as monitored on the oscilloscope maintained its proper shape and amplitude.

The EUT was considered to be susceptible when, in the presence of the fields or signals detailed for the respective test in MIL-STD 461D, the square wave:

- failed to hold its proper shape or amplitude;
- showed coupled noise in excess of the amplitude of the square wave;
- failed to operate

9.0 TEST PROCEDURES

9.1 Method CSI 14, Conducted Susceptibility, Bulk Cable Inj., 10 kHz- 30 MHz

9.1.1 Scope

The purpose of this test was to determine susceptibility of the EUT to signals injected on the power leads from 10 kHz- 30 MHz.

9.1.2 Test Setup and Procedure

The EUT was configured as shown in Figure 7.1. The EUT and all associated equipment was energized and proper operation of the EUT was verified. The procedure used for this test was according to that described in the M~-STD 462E).

The signal, a sinusoidal carrier modulated by a one volt peak to peak square wave, was injected at the point shown in Figure 9.1.1 at or exceeding the levels required by MIL-STD-461D (as shown in Figure 9.1.2) and swept across the required frequency range and monitored for susceptibility as described in Section 8.3 of this document. If a susceptibility was noted, the level at which the susceptibility was no longer present was determined and compared to the allowable limit for pass/fail determination.

Table 9.1.1 lists the equipment used during this test.
Figure 9.1.1 shows the EUT setup for test.
Figure 9.1.2 shows the applicable signal level for this test.
Figure 9.1.3 shows the signal generation and monitoring equipment.

This test was performed on both the input cable to the Gate Drive and on the cable between the Gate Drive and MCT. As it was not possible to separate out the return leads from the inputs cabling, the tests were run for bulk cable only.

Table 9.1.1 Equipment Used for CS114 Test

Item	Manufacturer	Model #	Serial #	Cal Due
Function Generator	Hewlett Packard	3325A	2847A07288	User
Function Generator	Hewlett Packard	8644A	3045A01306	User
Function Generator	Hewlett Packard	3314A	2836A12940	User
RF Power Amplifier	IFI	M404	04913986	N/A
RF Power Amplifier	IFI	M5500	N/A	N/A
Spectrum Analyzer	Hewlett Packard	8566B	3014A07039	Sept. 98
Spectrum Analyzer	Hewlett Packard	8591E	3325A01795	Sept. 97
Injection probe	Solar	9144-IN	942610	N/A
Monitor probe	Electrometrics	PCL-30	1128	Sept. 97
Directional coupler	Amplifier Research	DC2000	10823	N/A
Directional coupler	Amplifier Research	DC5000	10744	N/A
Coaxial Attenuator	Weinschel	471034	AZ6711	N/A
Coaxial Load	Bird	8164	13690	N/A
LISN	Fischer	LISN3	200	N/A

Table 9.1.1 Setup for CS 114 Test

Figure 9.1.2 CS114 Injection Level

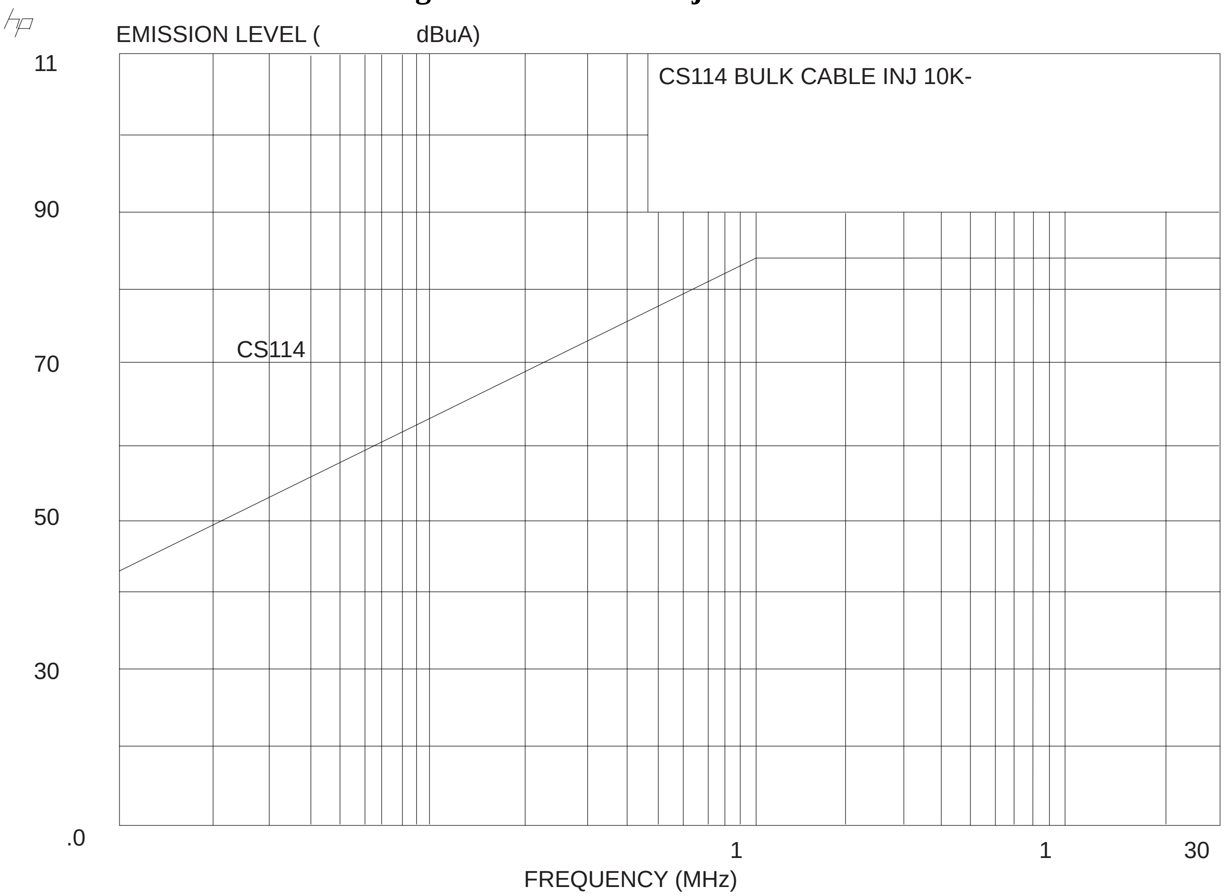


Figure 9.1.3 CS114 Generation & Monitoring Equipment

9.1.3 CS114 Test Results

Figure 9.1.4 shows the results for the Bulk Cable Injection; Gate Drive Cable.
Figure 9.1.5 shows the results for the Bulk Cable Injection; MCT Cable.

Injection on the Gate Drive Cable showed no significant degradation of the +/-15V square wave. When injecting on the MCT ribbon cable, there was no significant degradation below 25 kHz. Above that frequency, excessive noise appeared on the square wave (See Figure 9.1.6). The original ribbon cable going to the MCT was replaced with a shielded one and was retested, but showed similar results to the original configuration.

Figure 9.1.4: CS114 Data, Bulk Cable, Gate Drive Cable

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	28 Feb. 97
Model:	Prototype	**Mode:**	Gate Drive Cable, Bulk Cable

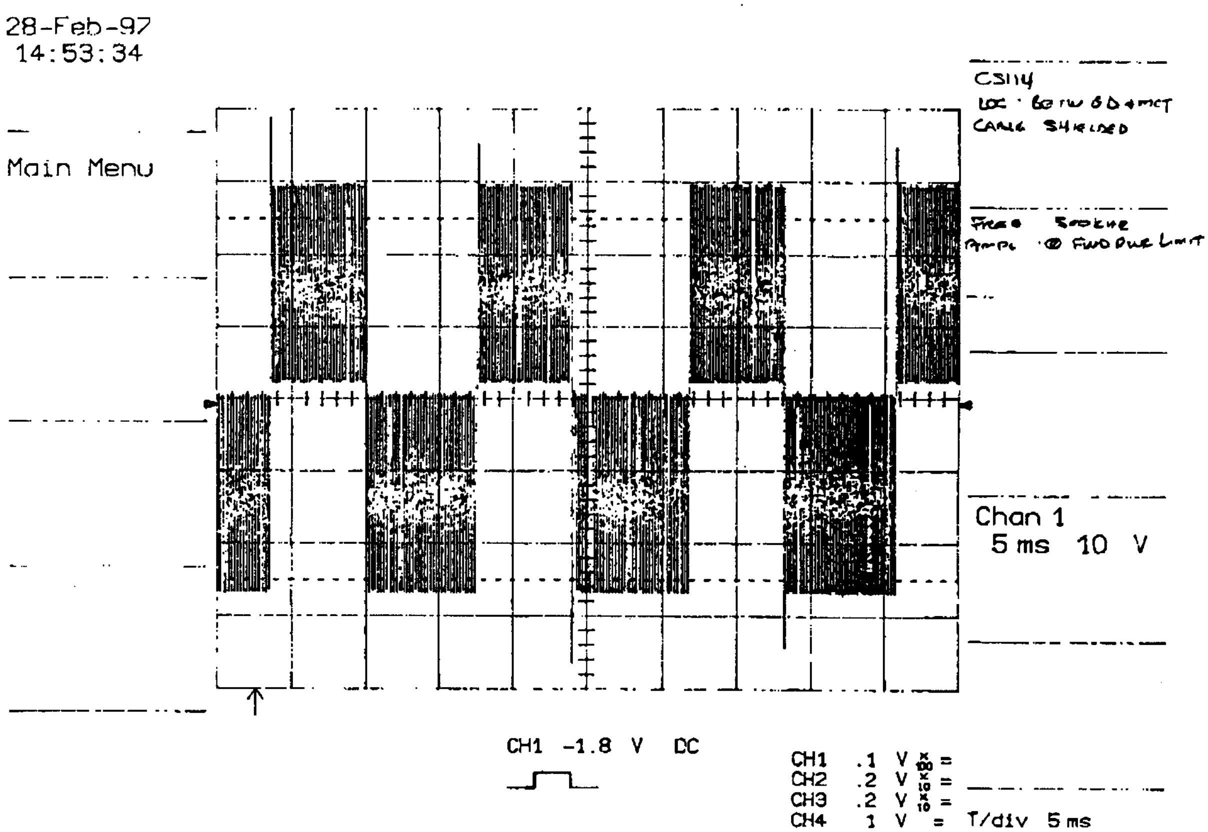
Frequency	Applied Signal	Pass/Fail	Remarks
10 kHz - 30 MHz	See Figure 9.1.2	Pass	No signs of malfunction or degradation

Figure 9.1.5: CS114 Data, Bulk Cable, MCT Cable

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	28 Feb. 97
Model:	Prototype	**Mode:**	Gate Drive Cable, Bulk Cable

Frequency	Applied Signal	Pass/Fail	Remarks
10 kHz - 30 MHz	See Figure 9.1.2	Fail	Coupled noise exceeded the amplitude of the square wave above 25 kHz

Figure 9.1.6: Coupled Noise When Injecting on MCT Cable



9.2 Method CS116, Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz

9.2.1 Scope

The purpose of this test was to determine susceptibility of the EUT to damped sinusoidal transients injected on the cabling from 10 kHz to 100 MHz.

9.2.2 Test Setup and Procedure

The EUT was configured as shown in Figure 7.1 The EUT and all associated equipment was energized and proper operation of the EUT was verified. The procedure used for this test was according to that described in the MIL-STD 462D.

The signal, a damped sinusoidal transient, was injected at the point on the cable nearest the EUT interface or connector at the frequencies and levels required by MIL-STD-461D (see Fig. 9.2.1) and monitored for susceptibility as described in Section 8.3. An alternate maximum input limit was derived, in accordance with MIL-STD-462D Method CS116, for instances where the required current specified in Figure 9.2.1 could not be generated due to the EUT's characteristic impedance. As per Paragraph 4b(1)-(5) of Method CS116, the maximum discharge voltage required to generate the current specified by Fig 9.2.1 into a 50 ohm load may be used as the maximum input limit. If a susceptibility was noted, the level at which the susceptibility was no longer present was determined and compared to the allowable limit for pass/fail determination.

Table 9.2.1 lists the equipment used during this test.
Figure 9.2.1 shows the applicable signal level for this test.
Figure 9.2.2 shows the signal generation and monitoring equipment.

Table 9.2.1 Equipment Used for CS116 Test

Item	Manufacturer	Model #	Serial #	Cal Due
Pulse Generator	Solar	9354	940508	User
Injection Probe	Solar	9127	3116A15646	User
Monitor probe	Solar	9123-1N	1128	Sept 97
Oscilloscope	Lecroy	9424	1563	Feb 97
Isolator	Tektronix	A6902B	B02208	Jul 98
Coaxial Attenuator	Weinschel	471034	AZ6711	N/A
Coaxial Load	Bird	8164	13690	N/A

Figure 9.2.1 CS116 Injection Level

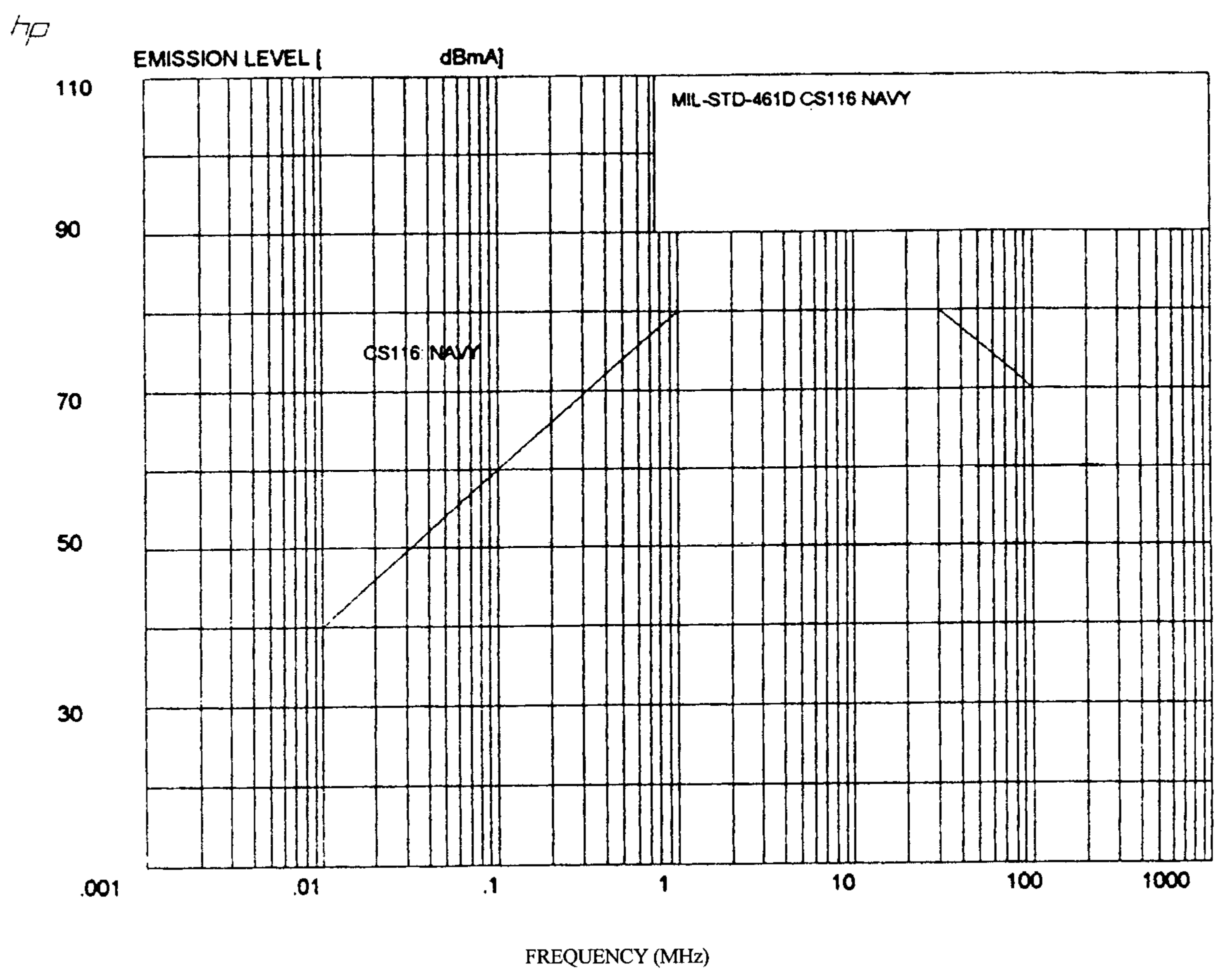
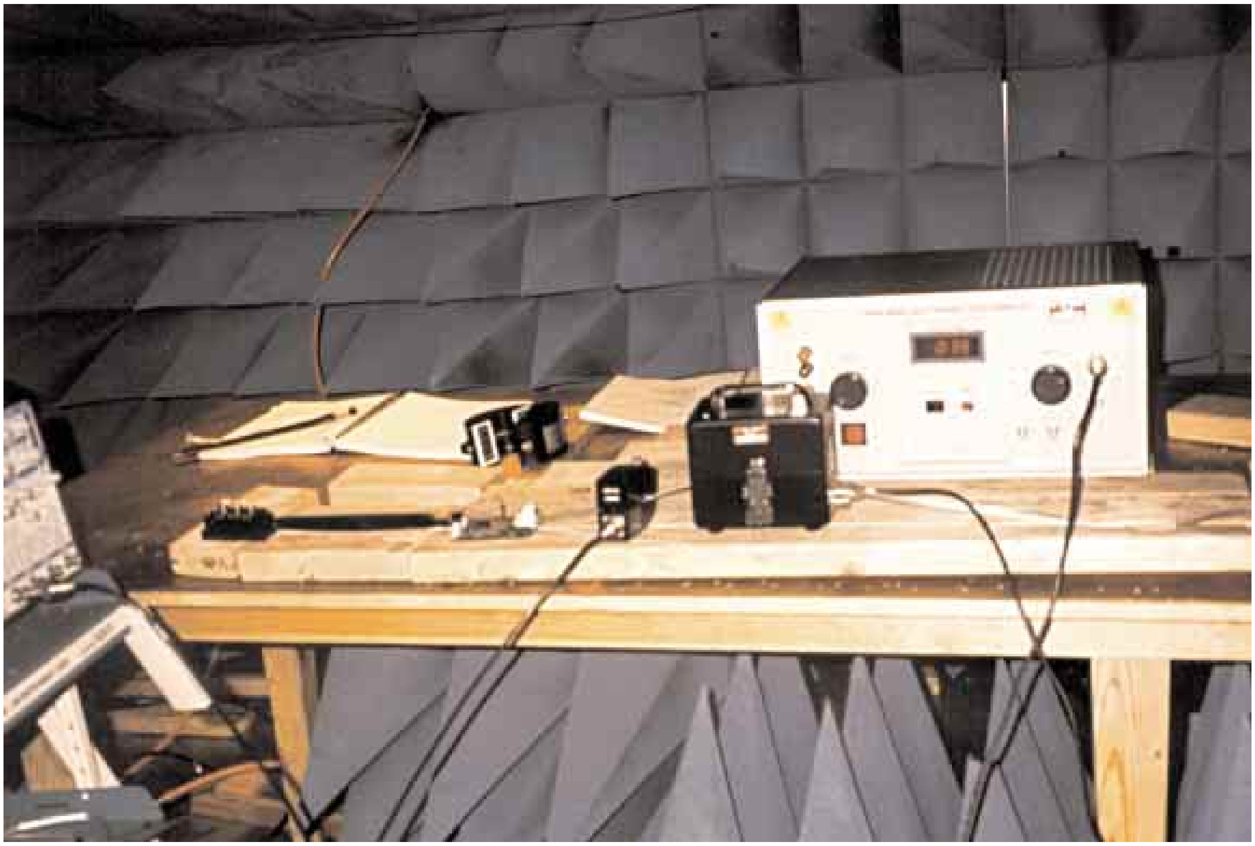


Figure 9.2.2: CS116 Test Setup



9.2.3 CS116 Results

This test was performed in accordance with the procedures listed MIL-STD-462D. The results of this test are listed and shown below.

Figure 9.2.3 shows the results for the Gate Drive input, bulk cable.

The required current was not able to be developed on this EUT so the alternate limit of the required current into a 50 ohm system was used. At each frequency the unit was first tested at 50% of the requirement then, if passing, the full requirement. At frequencies below 30 MHz, there was no susceptibility. At 30 MHz, the unit passed at the 50% level, but failed (destructively) at 100% of the required current. The test was halted to avoid damaging any further units.

Figure 9.2.3: CS116 Data, Gate Drive Cable

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	28 Feb. 97
Model:	Prototype	**Mode:**	Gate Drive Cable, Bulk Cable

Frequency Range	Required Transient Level (Amps)	Pass/Fail	Remarks
10 kHz	0.1	Pass	Used injection level for 50 ohm system
100 kHz	1.0	Pass	Used injection level for 50 ohm system
1 MHz	10.0	Pass	Used injection level for 50 ohm system
10 MHz	10.0	Pass	Used injection level for 50 ohm system
30 MHz	10.0	Fail	United passed upon first pulse injection at this frequency (50% of 50 ohm requirement) but failed to operate at 100% of requirement.
100 MHz	3.0	N/A	Not performed due to failure

9.3 Method RS101, Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz

9.3.1 Scope

The purpose of this test was to determine susceptibility of the EUT to radiated magnetic fields over the frequency range of 30 Hz -100 kHz.

9.3.2 Test Setup and Procedure

The EUT was configured as shown in Figure 7.1. The EUT and all associated equipment was energized and proper operation of the EUT was verified. The procedure used for this test was according to that described in the MIL-STD 462D.

The radiating loop was provided sufficient input signal to create output field strengths in excess of 10 dB above the applicable limit for this test, shown in Figure 9.3.1. For any susceptibility noted (as described in Section 8.3 of this document) a field strength corresponding to the applicable limit for this test was applied at the point at which the susceptibility was noted. A pass/fail determination was then made for the EUT based upon this result.

Table 9.3.1 lists the equipment used for this test.
Figure 9.3.1 shows the minimum AC current required to produce the required magnetic field using the radiating loop, with lines also designating 10 dB and 20 dB higher.
Figure 9.3.2 shows the RS101 test setup with typical radiating loop positioning.
Figure 9.3.3 shows the signal generation and monitoring equipment.

Table 9.3.1 Equipment Used for RS101 Test

Item	Manufacturer	Model #	Serial #	Cal Due
Function Generator	Hewlett Packard	3314A	2836A12940	User
Function Generator	Hewlett Packard	3314A	2836A12945	User
Audio Power Amplifier	Solar	6552-lA	932808	User
Audio Isolation Transformer	Solar	6220-lA	N/A	N/A
Radiating Loop	Eaton	96004	2141	May 98
Loop Sensor	Solar	9229-1	N/A	Apr 99
Current Probe	Electrometrics	PCL-11	1128	Mar 98
Spectrum Analyzer	Hewlett Packard	8566B	3014A07039	Sept 98
Preselector	Hewlett Packard	85865A	3010A01193	Sept 97
DMM	Fluke	87	85936	Jan 97
Isolation Transformer	Solar	7032-1	N/A	N/A

Figure 9.3.1 Graph of Applicable Limit for RS101

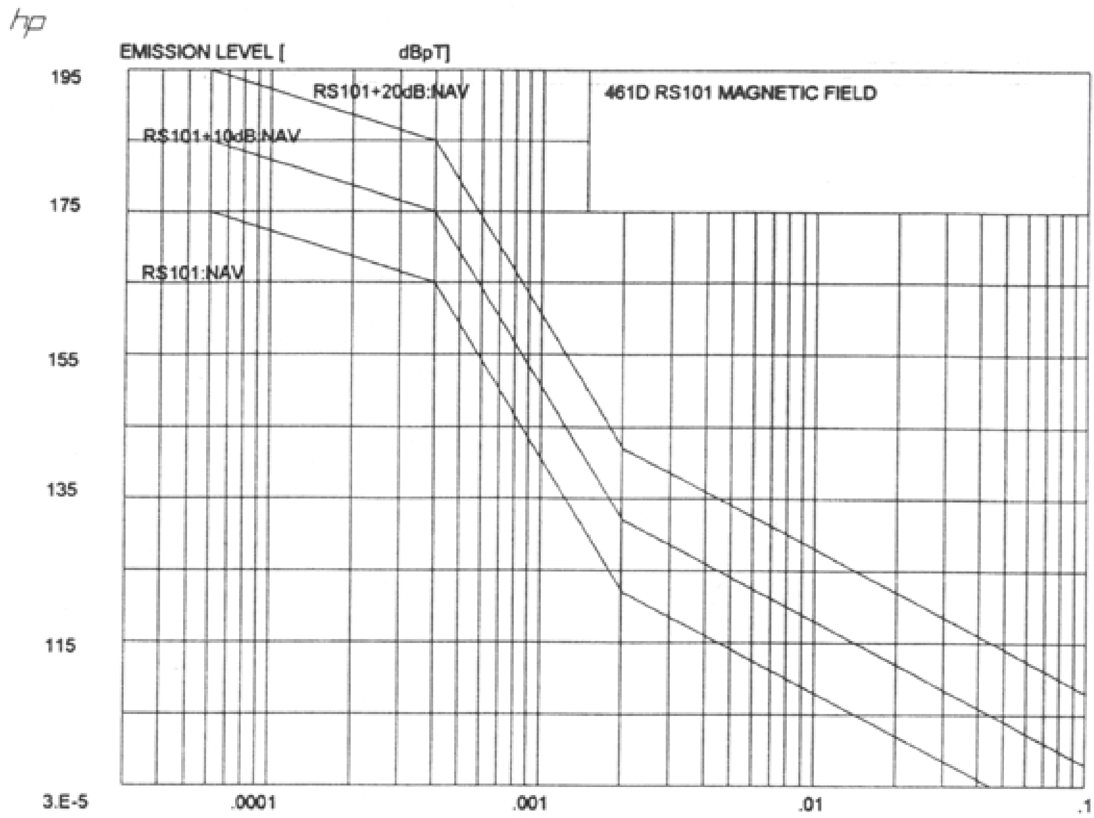


Figure 9.3.2 RS101 Test Setup

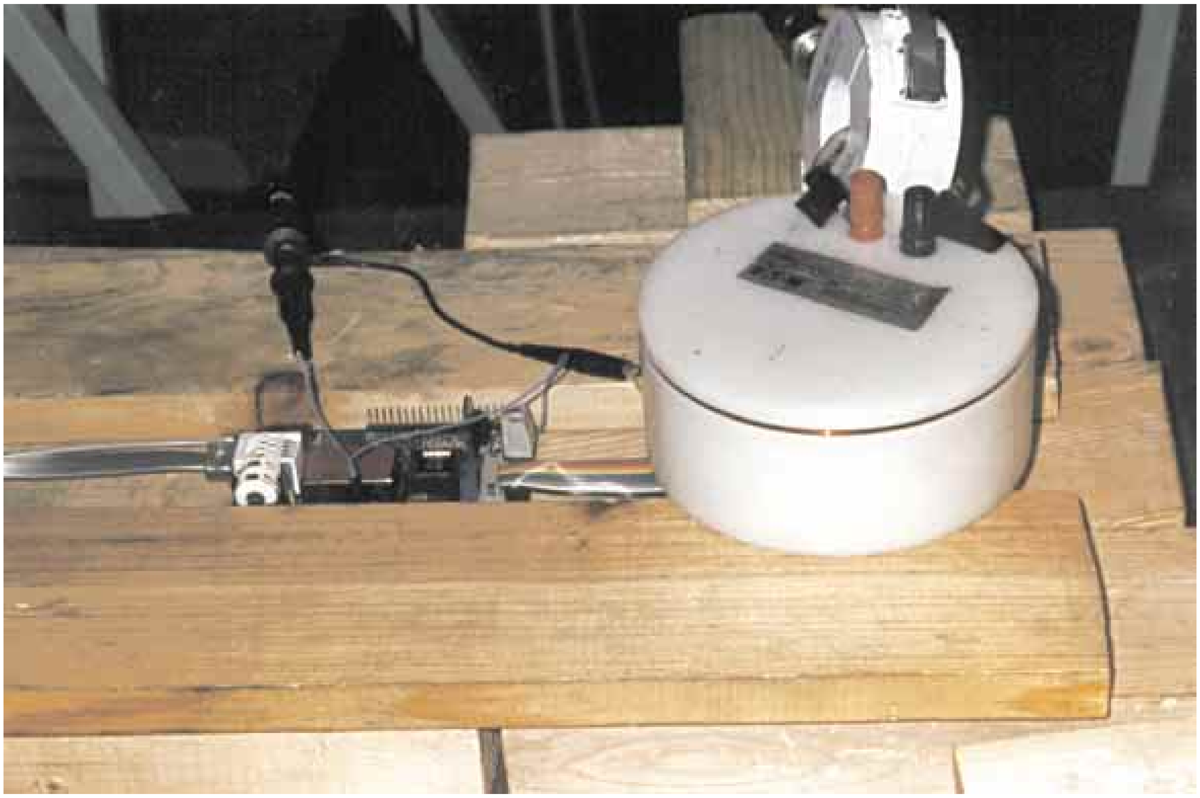
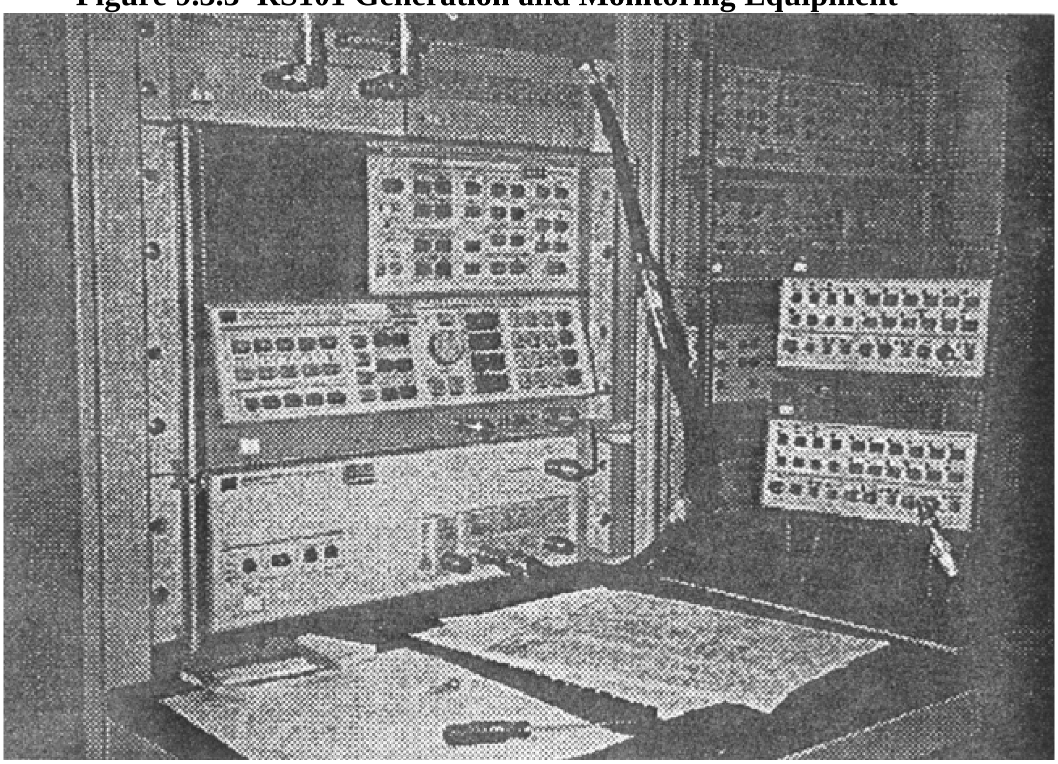


Figure 9.3.3 RS101 Generation and Monitoring Equipment



9.3.3 RS101 Test Results

Figure 9.3.4 shows the results for Gate Drive Circuit.
Figure 9.3.5 shows the results for the MCT.

This EUT is fully compliant with the RS101 requirement of MIL-STD-461D.

Figure 9.3.4: RS101 Data, Gate Drive

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	25 Feb 97
Model:	Prototype	**Mode:**	MCT Cable, Bulk Cable

Frequency Range	Min. Applied Signal (dBpT)	Pass/Fail	Remarks
30 Hz - 450 Hz	See Figure 9.3.1	Pass	No signs of malfunction or degradation
450 Hz - 30 kHz	See Figure 9.3.1	Pass	No signs of malfunction or degradation
30 kHz - 50 kHz	See Figure 9.3.1	Pass	No signs of malfunction or degradation

Figure 9.3.5: RS101 Data, MCT

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	25 Feb 97
Model:	Prototype	**Mode:**	MCT Cable, Bulk Cable

Frequency Range	Min. Applied Signal (dBpT)	Pass/Fail	Remarks
30 Hz - 450 Hz	See Figure 9.3.1	Pass	No signs of malfunction or degradation
450 Hz - 30 kHz	See Figure 9.3.1	Pass	No signs of malfunction or degradation
30 kHz - 50 kHz	See Figure 9.3.1	Pass	No signs of malfunction or degradation

9.4 Method RS103, Radiated Susceptibility, Electric Field, 10 kHz to 18 GHz

9.4.1 Scope

The purpose of this test was to determine susceptibility of the EUT to radiated electric fields in the range of 10 kHz to 18 GHz.

9.4.2 Test Setup and Procedure

The EUT was configured as shown in Figures 7.1 & 7.2. The EUT and all associated equipment were energized and proper operation of the EUT was verified. The procedure used for this test was according to that described in the MIL-STD-462D.

The electric fields were generated by signal generators producing a sinusoidal carrier which was modulated by a 1 volt peak to peak I kHz square wave. This signal was then amplified and fed to the various field producing antennae. The resultant fields were measured via a field sensing system which monitored and maintained the fields at or above the minimum levels agreed upon for this test.

The limit was specified at 10 volts per meter. Initial testing was performed at levels less than 10 V/m and increased until any susceptibility was observed.

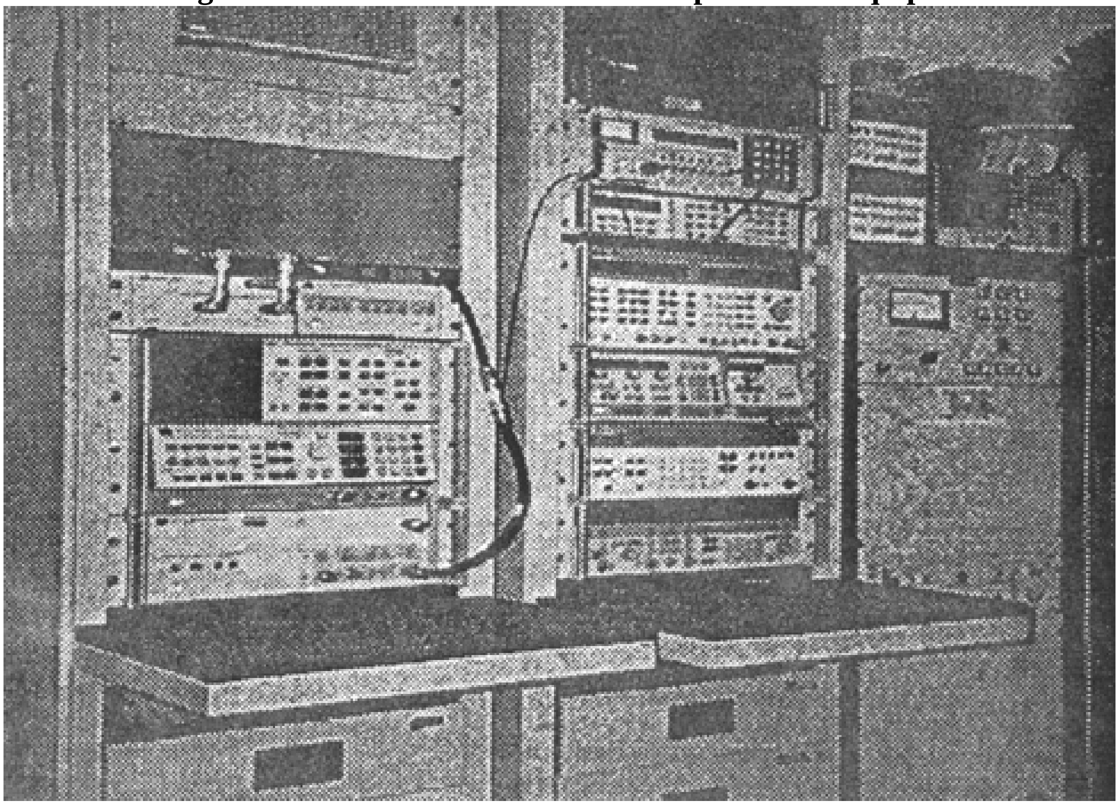
Table 9.4.1 lists the equipment used for this test.
Figure 9.4. I shows a typical setup (including radiating antenna and field sensor) for an RS 103 test.
Figure 9.4.2 shows the signal generation and amplification equipment used for this test.

Table 9.4 1 RS103 Test Equipment

Item	Manufacturer	Model #	Serial #	Cal Due
Signal Generator	Hewlett Packard	3325B	2847A07288	User
Signal Generator	Hewlett Packard	8350B	3116A15646	User
Signal Generator	Hewlett Packard	8644A	3045A01306	User
Signal Generator	Hewlett Packard	3314A	2836A12940	User
RF Amplifier	IFI	M404	04913986	N/A
RF amplifier	IFI	M5500	N/A	N/A
Microwave Amplifier	Hughes	8020H09	232	N/A
Microwave Amplifier	Hughes	8020H01	326	N/A
Microwave Amplifier	Hughes	8020H02_	312	N/A
Microwave Amplifier	Hughes	8020H03	284	N/A
Leveling Preamplifier	IFI	LPA-5	04913977	Oct 97
Parallel Element E Field Generator	Eaton	96003	2367	User
High Field Biconical	Electrometrics	BIA-30HF	2533	Sept 97
Double Ridged Waveguide (RF range)	Electrometrics	RGA-30	2457	Sept 97
Double Ridged Waveguide (Microwave range)	Electrometrics	RGA-60	3467	Sept 97
Field Sensor	IFI	EFS-5	491159	Nov 97
Field Probe	Narda	8721	04043	Aug 97

Figure 9.4.1 Typical RS103 Setup

Figure 9.4.2 RS103 Generation & Amplification Equipment



9.4.3 RS103 Test Results

Figure 9.4.3 shows the results for this EUT. This unit functioned acceptably from 14 kHz to 9 MHz. Above that frequency varying degrees of degradation to the square wave output was observed (a sample of which is shown as Fig. 9.4.4). The degree of degradation varied with the frequency and amplitude of the applied field but was generally present throughout the frequency range above 9 MHz. The test was halted at 200 MHz for this reason.

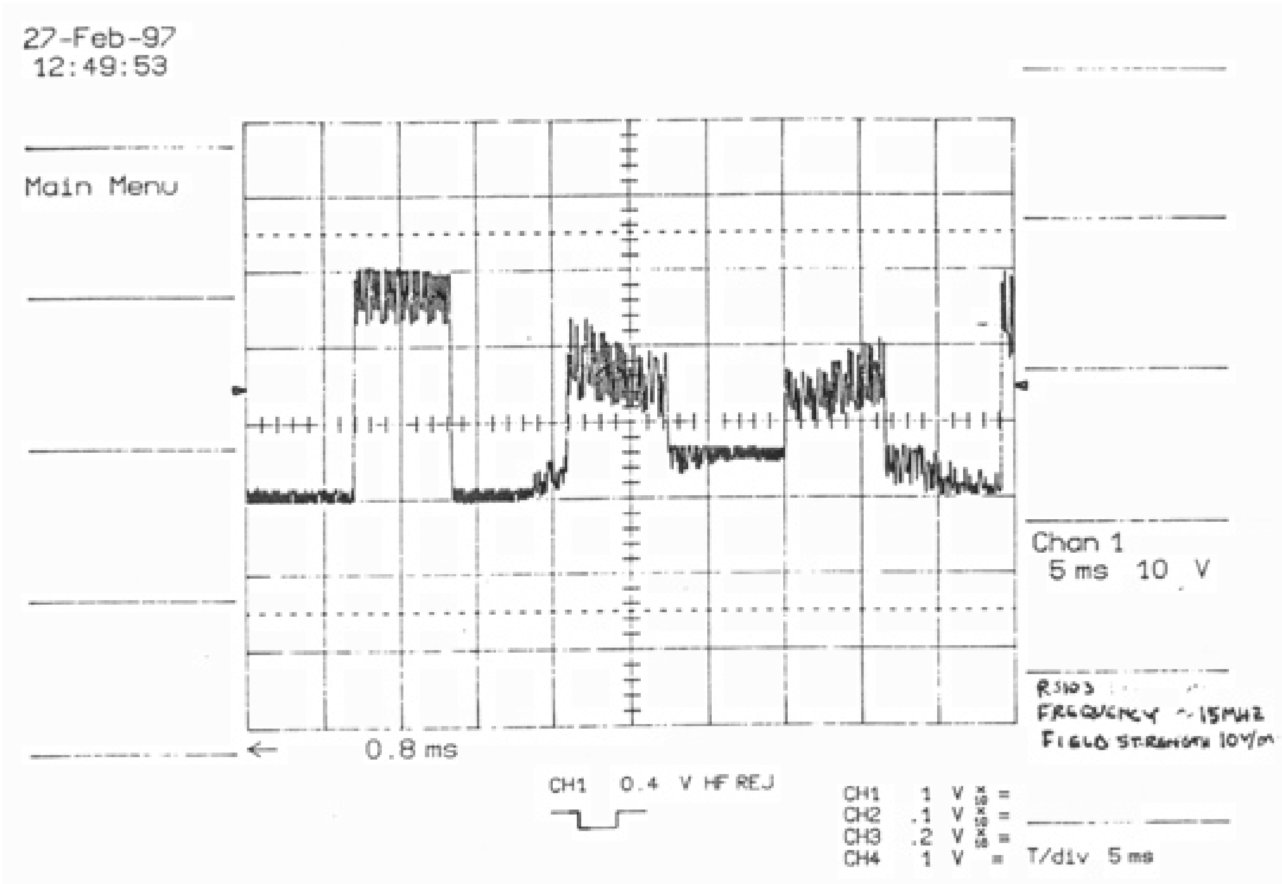
Figure 9.4.3 RS103 Results

Figure 9.1.5: CS114 Data, Bulk Cable, MCT Cable

EUT:	PEBB	**TEST:**	CS116
Mfr.:	Harris	**Date:**	27 Feb 97
Model:	Prototype	**Mode:**	Operating

Frequency (MHz)	Min. Applied Field Strength (Volts / Meter)	Pass/Fail	Remarks
.014 - 30	10	Fail	OK to 9 MHz; above 9 MHz amplitude of square wave drops; shape distorts.
30 - 200	10	Fail	Continuous degradation across this range with fields as low as 3 V/m
200 - 1000	10	N/A	Test halted due to degradation at 200 MHz
1000 - 18000	10	N/A	Test halted due to degradation at 200 MHz

Figure 9.4.4 Degradation of Signal Output Due to Radiated Fields



10.0 Conclusions

It should be first noted that the system as tested is far from its final configuration. There was no packaging of the circuits tested, leaving them exposed to any radiated fields. In its final configuration these circuits will be contained within some sort of enclosure which will likely change the radiated susceptibility characteristics considerably.

Also with regard to the conducted susceptibility testing, the cables upon which signals will be injected will be only those that protrude from the unit's enclosure. Therefore the data on the Gate Drive cable may have some relevance, but the data for the ribbon cable going to the MCT has far less value as it would be unlikely to be exposed for testing. Basically the value of the data collected during this testing is only to point out particular frequencies at which the follow on versions of the PEBB system may have difficulties.

This unit was not affected by the induced magnetic fields below 100 kHz.

This unit showed definite susceptibility to radiated electric fields above 9 MHz; however as stated above, the circuit was totally unprotected from the radiated fields, such that these results are of questionable value.

This unit showed no degradation to signals injected on the Gate Drive cable during the CS114 testing. While there were susceptibilities noted when injecting on the MCT cable, in a more developed configuration this cable will not likely be external to the unit and therefore not subject to injection. However, the use of a shielded cable in this location is rarely a bad idea.

Perhaps the most useful result from this testing was learning that the unit cannot withstand a 30 MHz electromagnetic pulse (at the level required by MIL-STD 461D) without failing. As the injection point upon which the failure was noted was the Gate Drive cable, which may well be subject to such pulses in any compliance testing, this may be an area in which the circuit needs additional protection.

Any further EMC testing of this unit should occur when the system has been packaged for shipboard use, or a close facsimile thereof. The possible exception being a retest of the CS116 requirement if any protection with regards to EMP is added to the circuit.